AD-A041 761 MISSION RESEARCH CORP SANTA BARBARA CALIF F/G 18/6

ANALYTIC SOLUTION OF A TEST PROBLEM FOR MODE.(U)

OCT 76 J L GILBERT, K S SMITH DNA001-77-C-0009

UNCLASSIFIED MRC-N-264 DNA-4145T NL

| OF |

AD
A041761

END

DATE
FILMED
8-77

DNA 4145T

ANALYTIC SOLUTION OF A TEST PROBLEM FOR MODE

Mission Research Corporation
735 State Street
Santa Barbara, California 93101

October 1976

Topical Report for Period 1 October 1976—30 October 1976

CONTRACT No. DNA 001-77-C-0009

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE B323077464 R99QAXEE50104 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER DNA 4145T	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYTIC SOLUTION OF A TEST PROBLEM FOR MODE		5. TYPE OF REPORT & PERIOD COVERED Topical Report, for Period 1 [redacted]–30 Oct 76
		6. PERFORMING ORG. REPORT NUMBER MRC-N-264
7. AUTHOR(s) James L. Gilbert Kenneth S. Smith		8. CONTRACT OR GRANT NUMBER(s) DNA 001-77-C-0009 New
9. PERFORMING ORGANIZATION NAME AND ADDRESS Mission Research Corp[redacted] 735 State Street Santa Barbara, Calif[redacted] 93101		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask R99QAXEE501-04
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE Oct[redacted]976
		13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) 26 p.		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B323077464 R99QAXEE50104 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SGEMP
Replacement Currents
Finite Difference

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes the analytic solution of a sphere driven by a radial current near the surface with a cosine angular distribution and a double exponential time history. This method was used to check the accuracy of the three-dimensional finite difference electromagnetics code MODE.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

406 548

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

SECTION 1

INTRODUCTION

In the validation of finite difference techniques it is often useful to have a test problem with an analytic solution so that a detailed comparison can be made. In this note we will derive the analytic expression for the fields outside a conducting sphere which is driven by a radial current in space between the surface of the sphere and an infinitesimal distance away from the surface. This current has a cosine distribution in the polar angle and a double exponential time history. We will also present graphs of the analytic results and a comparison with the results of MODE, a 3-D finite difference electromagnetics code with an outer boundary scheme based on a multipole expansion of outgoing waves. (In MODE, the current was driven in the first radial cell outside the sphere.)

SECTION 2

ANALYSIS

In solving for the fields outside a conducting sphere of radius a, excited by a radial current density,

$$J(r) = \hat{r}\, I(t) \cos\theta\, \delta(r-b) \quad , \tag{1}$$

we will use a Green's function technique and contour integration to determine the field time histories. We will first Fourier transform the driver

$$I(\omega) = \frac{1}{2\pi} \int_{-\infty}^{\infty} e^{+i\omega t} I(t) \quad , \tag{2}$$

where

$$\begin{aligned} I(t) &= e^{-\alpha t} - e^{-\beta t} \qquad t > 0\,, \beta > \alpha \\ &= 0 \qquad\qquad\qquad\quad t < 0 \end{aligned} \tag{3}$$

so

$$\begin{aligned} I(\omega) &= \frac{1}{2\pi} \int_{0}^{\infty} e^{(i\omega-\alpha)t} dt \\ &\quad - \frac{1}{2\pi} \int_{0}^{\infty} e^{(i\omega-\beta)t} dt \end{aligned} \tag{4}$$

$$= \frac{1}{2\pi} \left\{ - \frac{1}{i\omega - \alpha} + \frac{1}{i\omega - \beta} \right\} , \tag{5}$$

(I(t) is in amps/m.)

From the symmetry of the excitation we must only consider TM_{10} fields. This portion of the free space transverse Green's function can be written

$$\overleftrightarrow{G}_{TM10} = i\,k\,\vec{N}^{1}_{10}(r_<)\vec{N}^{3}_{10}(r_>) \ , \tag{6}$$

where

$$\vec{N}^{i}_{10} = \hat{r}\sqrt{2}\,\frac{z^{i}_{1}(kr)}{kr}\,Y_{10}(\theta,\phi) + \frac{1}{kr}\,[kr\,z^{i}_{1}(kr)]'\,\vec{K}'_{10}(\theta,\phi) \ , \tag{7}$$

with

$$\left.\begin{aligned} z^{1}_{1}(kr) &= j_1(kr) \\ z^{3}_{1}(kr) &= h^{(1)}_{1}(kr) \\ Y_{10}(\theta,\phi) &= \sqrt{\frac{3}{4\pi}}\cos\theta \\ \vec{K}'_{10}(\theta,\phi) &= \frac{1}{\sqrt{2}}\,\hat{\theta}\,\frac{\partial Y_{10}}{\partial\theta} = -\,\hat{\theta}\sqrt{\frac{3}{8\pi}}\sin\theta \ . \end{aligned}\right\} \tag{8}$$

The vanishing of the tangential electric field on the boundary can be ensured by adding to the free space Green's function a term

$$\overleftrightarrow{G}'_{TM10} = -\,i\,k\,\frac{[kaj_1(ka)]'}{[kah^{(1)}_{1}(ka)]'}\,\vec{N}^{3}_{10}(r_>)\vec{N}^{3}_{10}(r_<) \ . \tag{9}$$

This part has

$$\vec{\nabla}\times(\vec{\nabla}\times\overleftrightarrow{G}') - k^2\overleftrightarrow{G} = 0 \ , \tag{10}$$

outside the sphere and a theta component which is the negative of that for the free space Green's function at the surface of the sphere r = a. Since

$$\vec{\nabla}\times\vec{\nabla}\times\vec{E} - k^2\vec{E} = i\omega\mu\vec{J} \ , \tag{11}$$

we have

$$\vec{E}(r) = i\omega\mu\int dV'\,\overleftrightarrow{G}(r,r')\cdot\vec{J}(r') \tag{12}$$

Inserting Equation 5 into this, we will first look at fields beyond the source, so the electric field will be

$$\vec{E} = \left[\hat{r}\sqrt{2}\,\frac{h_1^{(1)}(kr)}{kr}\sqrt{\frac{3}{4\pi}}\cos\theta - \hat{\theta}\,\frac{[krh_1^{(1)}(kr)]'}{kr}\sqrt{\frac{3}{8\pi}}\sin\theta\right]$$

$$\times\ (-k\omega\mu)\int r'^2 dr'd(\cos\theta')d\phi\,\sqrt{2}\,\frac{1}{kr'}\sqrt{\frac{3}{4\pi}}\cos\theta'$$

$$\times \left\{ j_1(kr') - \frac{[kaj_1(ka)]'}{[kah_1^{(1)}(ka)]'}\,h_1^{(1)}(kr') \right\} I_\omega \cos\theta'\delta(r'-b)\ . \tag{13}$$

On performing the integral

$$E = \left[\hat{r}\sqrt{2}\,\frac{h_1^{(1)}(kr)}{kr}\sqrt{\frac{3}{4\pi}}\cos\theta - \hat{\theta}\,\frac{[krh_1^{(1)}(kr)]'}{kr}\sqrt{\frac{3}{8\pi}}\sin\theta\right](-\omega\mu)(2\pi)$$

$$\times\ (\tfrac{2}{3})\,\sqrt{2}\sqrt{\frac{3}{4\pi}}\,I_\omega b\left\{ j_1(kb) - \frac{[kaj_1(ka)]'}{[kah_1^{(1)}(ka)]'}\,h_1^{(1)}(kb) \right\}\ , \tag{14}$$

$$E_r = -\,2\,\frac{c\mu b}{r}\,I_\omega h_1^{(1)}(kr)\left\{\quad\right\}\cos\theta\ , \tag{15}$$

$$E_\theta = +\,\frac{c\mu b}{r}\,I_\omega [krh_1^{(1)}(kr)]'\left\{\quad\right\}\sin\theta\ , \tag{16}$$

$$H_\phi = +\,ikbI_\omega h_1^{(1)}(kr)\left\{\quad\right\}\sin\theta\ . \tag{17}$$

Note that $c\mu_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = Z_0$, the impedance of free space.

Please note that this formulation is inadequate to treat the fields in the first cell anyway since we are measuring the electric field in the same mesh zone where we are driving the currents. (We will return to this point later.) We wish to do the integral

$$E(t) = \int_{-\infty}^{\infty} d\omega E(\omega) e^{-i\omega t} = c \int_{-\infty}^{\infty} dk E(k) e^{-ickt} \quad , \tag{18}$$

so it is necessary for us to examine the singularity structure of the integrand.

The term in brackets will have poles at the roots of

$$[kah_1^{(1)}(ka)]' = 0 \quad , \tag{19}$$

which are

$$k = \pm \frac{\sqrt{3}}{2a} - \frac{i}{2a} \quad . \tag{20}$$

We also have singularities at the poles of I_k

$$\begin{aligned} k &= - i\alpha/c \\ k &= - i\beta/c \quad . \end{aligned} \tag{21}$$

To examine the behavior at the origin we expand for small k

$$\left.\begin{aligned} & j_1(kr) \to \frac{kr}{3} \\ & h_1^{(1)}(kr) \to in_1(kr) \to - \frac{i}{k^2 r^2} \\ & [krj_1(kr)]' \to \frac{2kr}{3} \\ & [krh_1^{(1)}(kr)]' \to + \frac{i}{k^2 r^2} \quad , \end{aligned}\right\} \tag{22}$$

and find that the term in braces in (14) behaves as

$$\left\{ \quad \right\} \to kb \left\{ \frac{1}{3} + \frac{2}{3} \frac{a^3}{b^3} \right\} \quad . \tag{23}$$

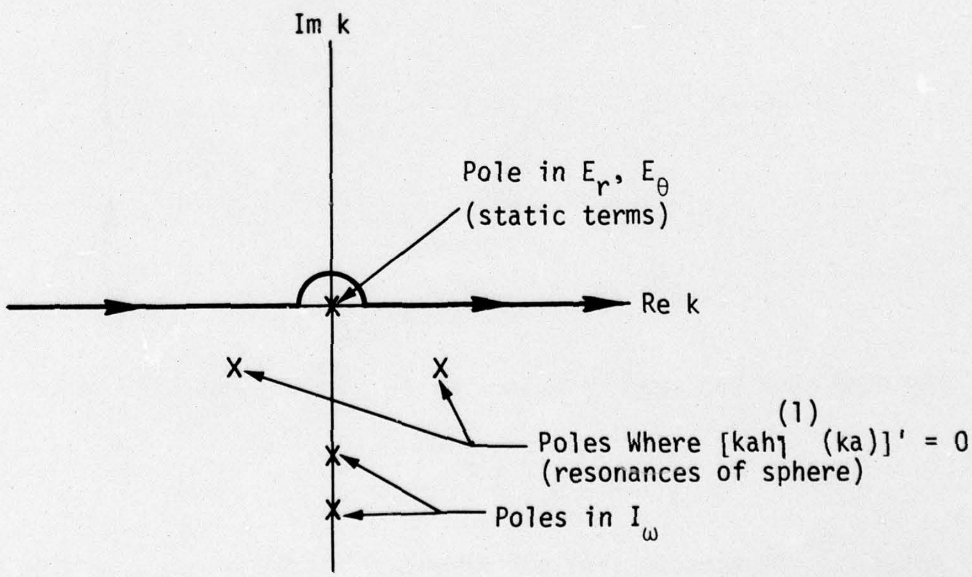
Since I_ω is nonzero (but not singular) at the origin, we find that there are first order poles at the origin for E_r and E_θ but not for H_ϕ.

This is physically reasonable as it corresponds to the static fields which exist at late times in the problem.

We now turn to the behavior for large k and the evaluation of the time response by contour integration. For large k

$$\left.\begin{aligned}
j_1(kr) &\longrightarrow -\frac{1}{2kr}\left(e^{ikr} + e^{-ikr}\right) \\
[krj_1(kr)]' &\longrightarrow -\frac{i}{2}\left(e^{ikr} - e^{-ikr}\right) \\
h_1^{(1)}(kr) &\longrightarrow -\frac{1}{kr}\, e^{ikr} \\
[krh_1^{(1)}(kr)]' &\longrightarrow -\, ie^{ikr} \ .
\end{aligned}\right\} \qquad (24)$$

We choose the contour of integration from casuality considerations so that we have the static fields at late times and no fields for $t < 0$.



We must break time into three steps to distort our contours.

$$ct < r - b$$

$$r - b < ct < r + b - 2a$$

$$r + b - 2a < ct \ .$$

For $ct < r - b$ we close the contour with a semicircle in the upper half-plane. The integrand on this contour behaves as

$$\frac{1}{k^4} e^{ik(r-b-ct)} \quad \text{for } E_r \ , \ E_\theta$$

$$\frac{1}{k^3} e^{ik(r-b-ct)} \quad \text{for } H_\phi \ ,$$

and so $\rightarrow 0$ as we let the radius become infinite. Therefore

$$E_r \ , \ E_\theta \ , \ H_\phi = 0 \qquad ct < r - b \ .$$

For $r - b < ct < r + b - 2a$ we must break the integrand into two pieces. We see this most easily by writing the braces out in terms of $h_1^{(1)}(kr)$ and $h_1^{(2)}(kr)$

$$\left\{ \ \right\} = \frac{1}{2} h_1^{(2)}(kb) - \frac{1}{2} \frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'} h_1^{(1)}(kb) \ . \tag{25}$$

These two portions of the integrand have exponential behavior like

$$e^{ik(r-ct-b)} \quad \text{and} \quad e^{ik(r-ct+b-2a)} \ ,$$

so that, for $r - b < ct < r + b - 2a$, we close the contour on the first portion with a semicircle in the lower half plane, but close the second portion of the integrand in the upper half plane. This is physically reasonable, for at this time the observer at r sees the current but there is not yet sufficient time for reflections of the radiated field from the

current off of the sphere to reach the observer. Note that the portions of the integrand contributing are the same as they would be for the current without the conducting sphere. Note also that this division of terms in the integrand produce a pole at $k = 0$ in the expression for B. This will not exist in the late time expression, $ct > r - 2a + b$. We encircle the poles at the origin and the poles of I_ω.

For the E's we have a fourth order pole at the origin from the first term and for H_ϕ a third order pole at the origin.

$$E_r = + \frac{ic^2\mu}{r^3 b} \frac{1}{3!} \frac{d^3}{dk^3} \left\{ \frac{1}{ick-\beta} - \frac{1}{ick-\alpha} \right\} e^{-ickt} \bigg|_{k=0} \cos\theta$$

$$+ \frac{c\mu b}{r} h_1^{(1)}(kr) h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\beta}{c}} \cos\theta \tag{26}$$

$$- \frac{c\,b}{r} h_1^{(1)}(kr) h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\alpha}{c}} \cos\theta \,,$$

$$E_\theta = + \frac{i\mu c^2}{2r^3 b} \sin\theta \frac{1}{3!} \frac{d^3}{dk^3} \left\{ \frac{1}{ick-\beta} - \frac{1}{ick-\alpha} \right\} e^{-ickt} \bigg|_{k=0}$$

$$- \frac{c\mu b}{2r} \sin\theta \, [krh_1^{(1)}(kr)]' h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\beta}{c}} \tag{27}$$

$$+ \frac{c\mu b}{2r} \sin\theta \, [krh_1^{(1)}(kr)]' h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\alpha}{c}} \,,$$

$$H_\phi = \frac{c}{2r^2 b} \sin\theta \frac{1}{2!} \frac{d^2}{dk^2} \left\{ \frac{1}{ick-\beta} - \frac{1}{ick-\alpha} \right\} e^{-ickt} \bigg|_{k=0}$$

$$- \frac{ikb}{2} \sin\theta \, h_1^{(1)}(kr) h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\beta}{c}} \tag{28}$$

$$+ \frac{ikb}{2} \sin\theta \, h_1^{(1)}(kr) h_1^{(2)}(kb) e^{-ickt} \bigg|_{k=-\frac{i\alpha}{c}} \,.$$

Finally we have for $ct > r + b - 2a$, where we only have a first order pole at the origin for E_r, E_θ and none at all for H_ϕ, the following expressions.

$$[kah_1^{(1)}(ka)]' = -\frac{i}{(ka)^2} e^{ika}\left(ka + \frac{\sqrt{3}}{2} + \frac{i}{2}\right)\left(ka - \frac{\sqrt{3}}{2} + \frac{i}{2}\right) \tag{29}$$

$$E_r = \frac{2c^2\mu b^2}{r^3}\left[\frac{1}{3} + \frac{2}{3}\frac{a^3}{b^3}\right] \cos\theta\left\{\frac{1}{\alpha} - \frac{1}{\beta}\right\}$$

$$+ \frac{c^2 a\mu b}{r}\cos\theta\left\{\frac{1}{ick-\beta} - \frac{1}{ick-\alpha}\right\}\frac{k^2 h_1^{(1)}(kr)h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka - \frac{\sqrt{3}}{2} + i/2}$$

$$\times e^{-ickt-ika}\Big|_{k = -\frac{\sqrt{3}}{2a} - \frac{i}{2a}}$$

$$+ \frac{c^2 a\mu b}{r}\cos\theta\left\{\frac{1}{ick-\beta} - \frac{1}{ick-\alpha}\right\}\frac{k^2 h_1^{(1)}(kr)h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka + \frac{\sqrt{3}}{2} + i/2}$$

$$\times e^{-ickt-ika}\Big|_{k = +\frac{\sqrt{3}}{2a} - \frac{i}{2a}}$$

$$+ \frac{c\mu b}{r}\cos\theta\, h_1^{(1)}(kr)\left\{h_1^{(2)}(kb) - \frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times e^{-ickt}\Big|_{k = -\frac{i\beta}{c}}$$

$$- \frac{c\mu b}{r}\cos\theta\, h_1^{(1)}(kr)\left\{h_1^{(2)}(kb) - \frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times e^{-ickt}\Big|_{k = -\frac{i\alpha}{c}}, \tag{30}$$

$$E_\theta = \frac{c^2\mu b^2}{r^3}\left\{\frac{1}{\alpha} - \frac{1}{\beta}\right\}\left(\frac{1}{3} + \frac{2}{3}\frac{a^3}{b^3}\right)\sin\theta$$

$$- \frac{c^2 a\mu b}{2r}\sin\theta\left\{\frac{1}{ick-\beta} - \frac{1}{ick-\alpha}\right\}\frac{k^2[krh_1^{(1)}(kr)]'h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka - \frac{\sqrt{3}}{2} + i/2}$$

$$\times e^{-ickt-ika}\Big|_{k=-\frac{\sqrt{3}}{2a}-\frac{i}{2a}}$$

$$- \frac{c^2 a\mu b}{2r}\sin\theta\left\{\frac{1}{ick-\beta} - \frac{1}{ick-\alpha}\right\}\frac{k^2[krh_1^{(1)}(kr)]'h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka + \frac{\sqrt{3}}{2} + i/2}$$

$$\times e^{-ickt-ika}\Big|_{k=-\frac{\sqrt{3}}{2a}-\frac{i}{2a}}$$

$$- \frac{c\mu b}{2r}\sin\theta[krh_1^{(1)}(kr)]'\left\{h_1^{(2)}(kb) - \frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times e^{-ickt}\Big|_{k=-\frac{i\beta}{c}}$$

$$+ \frac{c\mu b}{2r}\sin\theta[krh_1^{(1)}(kr)]'\left\{h_1^{(2)}(kb) - \frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times e^{-ickt}\Big|_{k=-\frac{i\alpha}{c}}, \qquad (31)$$

$$H_\phi = -\frac{ibca}{2}\sin\theta\left\{\frac{1}{ick-\beta}-\frac{1}{ick-\alpha}\right\}\frac{k^3h_1^{(1)}(kr)h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka-\frac{\sqrt{3}}{2}+i/2}$$

$$\times\, e^{-ickt-ika}\Big|_{k=-\frac{\sqrt{3}}{2a}-\frac{i}{2a}}$$

$$-\frac{ibca}{2}\sin\theta\left\{\frac{1}{ick-\beta}-\frac{1}{ick-\alpha}\right\}\frac{k^3h_1^{(1)}(kr)h_1^{(1)}(kb)[kah_1^{(2)}(ka)]'}{ka+\frac{\sqrt{3}}{2}+i/2}$$

$$\times\, e^{-ickt-ika}\Big|_{k=+\frac{\sqrt{3}}{2a}-\frac{i}{2a}}$$

$$-\frac{ib}{2}\sin\theta kh_1^{(1)}(kr)\left\{h_1^{(2)}(kb)-\frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times\, e^{-ickt}\Big|_{k=-\frac{i\beta}{c}}$$

$$+\frac{ib}{2}\sin\theta kh_1^{(1)}(kr)\left\{h_1^{(2)}(kb)-\frac{[kah_1^{(2)}(ka)]'}{[kah_1^{(1)}(ka)]'}h_1^{(1)}(kb)\right\}$$

$$\times\, e^{-ickt}\Big|_{k=-\frac{i\alpha}{c}}\,. \tag{32}$$

As a check of algebra, we will calculate the late-time static behavior of E_r and E_θ for $b = a$. (H_ϕ will decay to zero at late times.) The late time fields are given in terms of the dipole moment as

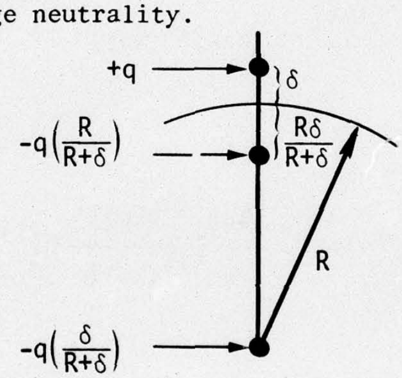
$$\left.\begin{aligned} E_r &= \frac{2D_z}{4\pi\varepsilon_0 r^3}\cos\theta \\ E_\theta &= \frac{D_z}{4\pi\varepsilon_0 r^3}\sin\theta\,, \end{aligned}\right\} \tag{33}$$

where

$$D_z \doteq \int dV \rho z = \int dt \int dV\, \vec{J} \cdot \hat{z}$$

$$= \int dt \int dV\, J_r \cos\theta \ , \qquad (34)$$

as we have no J_θ. We now use a quasistatic calculation to relate the dipole moment induced on the sphere to that of the charge distribution in space. We move a charge +q an infinitesimal distance from the surface, leaving a -q at the point on the surface from which the +q was emitted. The dipole moment from the motion of charge in space is $q\delta$. However the sphere will polarize and change this dipole moment. We can treat this polarization by using image charges; a charge at the center of the sphere must be added to preserve total charge neutrality.



The dipole moment for this set of charges is

$$D_{sph} = q\delta + q\delta \left(\frac{R}{R+\delta}\right)^2 + q\delta \left(\frac{R}{R+\delta}\right) \xrightarrow[\delta \to 0]{} 3q\delta \ , \qquad (35)$$

so that the effect of the polarization of the sphere is to triple the total dipole moment when compared with that of just the charge motion in space. Calculating the latter dipole moment from (1) and (34)

$$D = \left\{\frac{1}{\alpha} - \frac{1}{\beta}\right\} \frac{4\pi}{3} b^2 \ , \qquad (36)$$

so that the late time fields should be

$$E_r = \frac{2b^2}{\varepsilon_0 r^3}\left(\frac{1}{\alpha} - \frac{1}{\beta}\right) \cos\theta \ ,$$

$$E_\theta = \frac{b^2}{\varepsilon_0 r^3}\left(\frac{1}{\alpha} - \frac{1}{\beta}\right) \sin\theta \ , \tag{37}$$

which is what we obtained as $c^2\mu_0 = 1/\varepsilon_0$.

When we utilize these results for the comparison with the code, we must do two things:

1. Specify the driver in terms of the code dipole strength. By consideration of Stokes' theorem we see that the driver in the code is not a delta function in r but a finite length Δr. This means that our far fields should be multiplied by Δr. The dispersive effects in finite difference calculations prevent an accurate calculation of effects when $\lambdabar$ is much smaller than the mesh cell dimensions in the direction of propagation.

2. Specify how to calculate the radial electric field in the innermost mesh. To compare with the finite differencing scheme, we must consider the finite length of the driver and the mesh. The prescription that we choose to handle this is to examine our fields in the limit $a \rightarrow b$ and take H_ϕ from the outside limit. We find the first mesh cell E_r from the outside field with a correction term arising from the charge density

$$E_r = E_r(r \rightarrow b) - f(t) \cos\theta \ , \tag{38}$$

where

$$f(t) = \frac{1}{\varepsilon_0}\int_0^t dt' I(t')$$

$$= \frac{1}{\varepsilon_0 \alpha}\left\{1 - e^{-\alpha t}\right\} - \frac{1}{\varepsilon_0 \beta}\left\{1 - e^{-\beta t}\right\} \ . \tag{39}$$

Finally we write the equations in the units used in MODE. The excitation factor must be converted by

$$1 \text{ Abamp/cm}^2 = 10^5 \text{ Amps/m}^2 , \tag{40}$$

and the fields by

$$\begin{aligned} &1 \text{ statvolt/cm} = 3 \times 10^4 \text{ volts/m} \\ &1 \text{ gauss} = 79.58 \text{ Amps/m} , \end{aligned} \tag{41}$$

so we define

$$\left.\begin{aligned} F_1 &= 7.41 \times 10^3 \\ F_2 &= 10^5 \\ G_1 &= 3.33 \times 10^{-5} \\ G_2 &= 1.26 \times 10^{-2} \end{aligned}\right\} \tag{42}$$

For fields outside the source region

$$\begin{aligned} (E_r^{esu}, E_\theta^{esu}) &= F_1 G_1 (E_r, E_\theta) \\ H_\phi^{esu} &= F_1 G_2 H_\phi , \end{aligned} \tag{43}$$

and for fields in the first cell.

$$\begin{aligned} E_r^{esu} &= F_1 G_1 E_r - F_2 G_1 f(t) \cos\theta \\ H_\phi^{esu} &= F_1 G_2 H_\phi . \end{aligned} \tag{44}$$

SECTION 3

RESULTS AND COMPARISON WITH MODE

In this section we present graphs of the electric and magnetic fields previously calculated. The surface radial and magnetic fields need no explanation; the theta electric field is shown at 1.074 meters as that is the first mesh point at which this field is non-vanishing in MODE. The fields are also shown at 2 meters which is the outer boundary in MODE. In Table 1 we present a comparison between the analytic calculation and the finite difference of the values and times of various features seen in Figures 1 through 6. The peaks and dips are broad so that the times given are not too relevant.

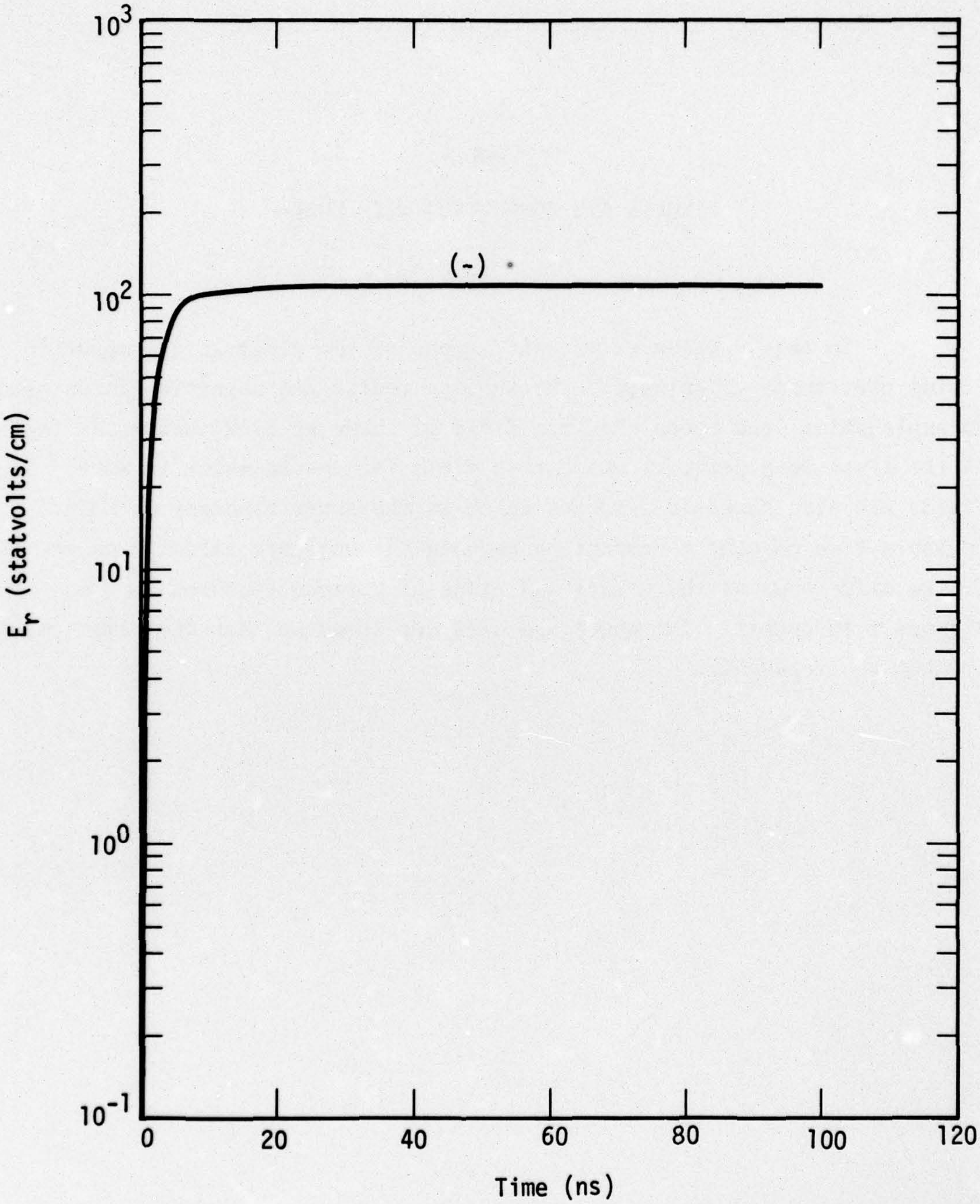


Figure 1. Radial electric field at r = 1 m, θ = 0°.

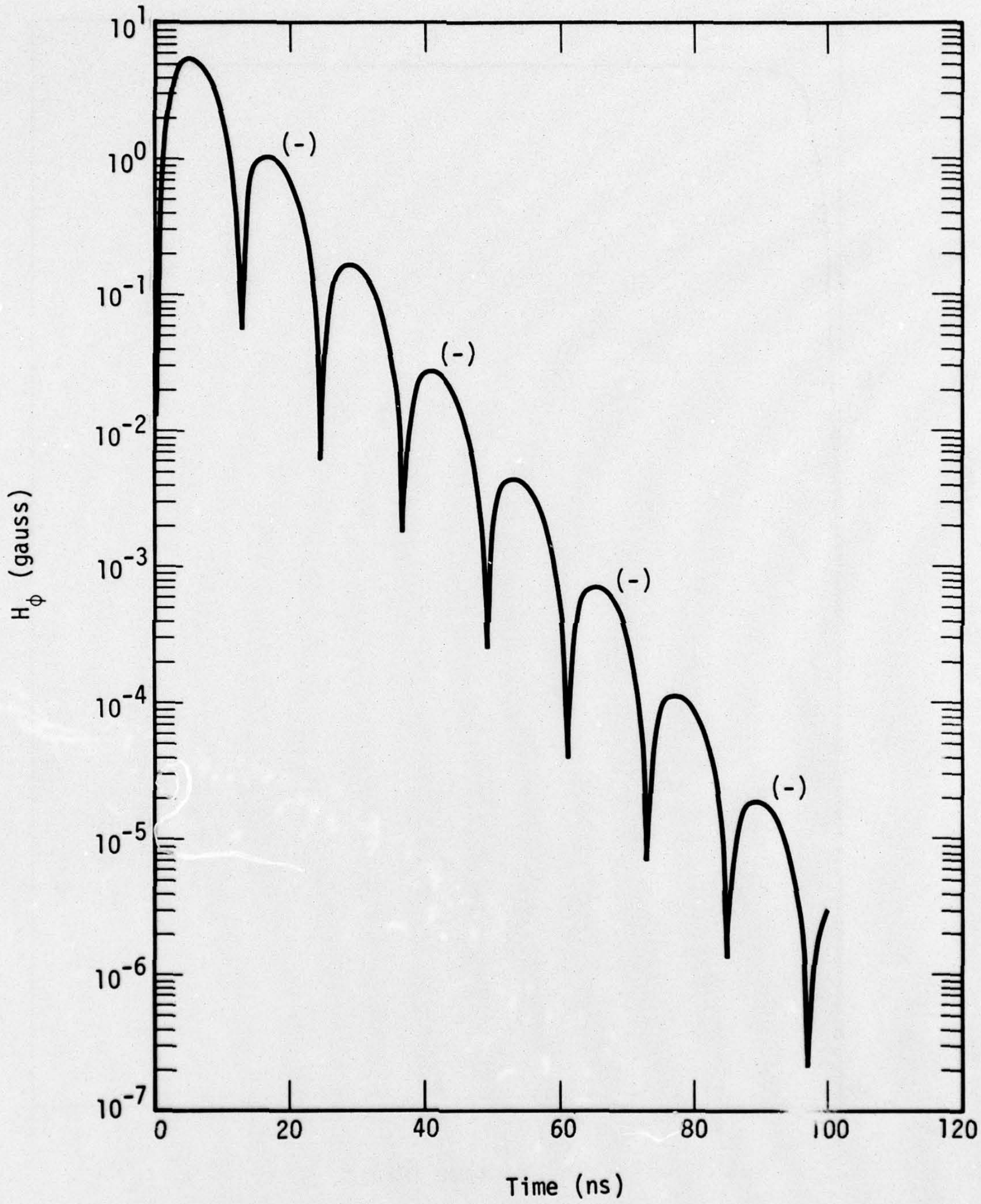


Figure 2. Azimuthal magnetic field at r = 1 m, θ = 90°.

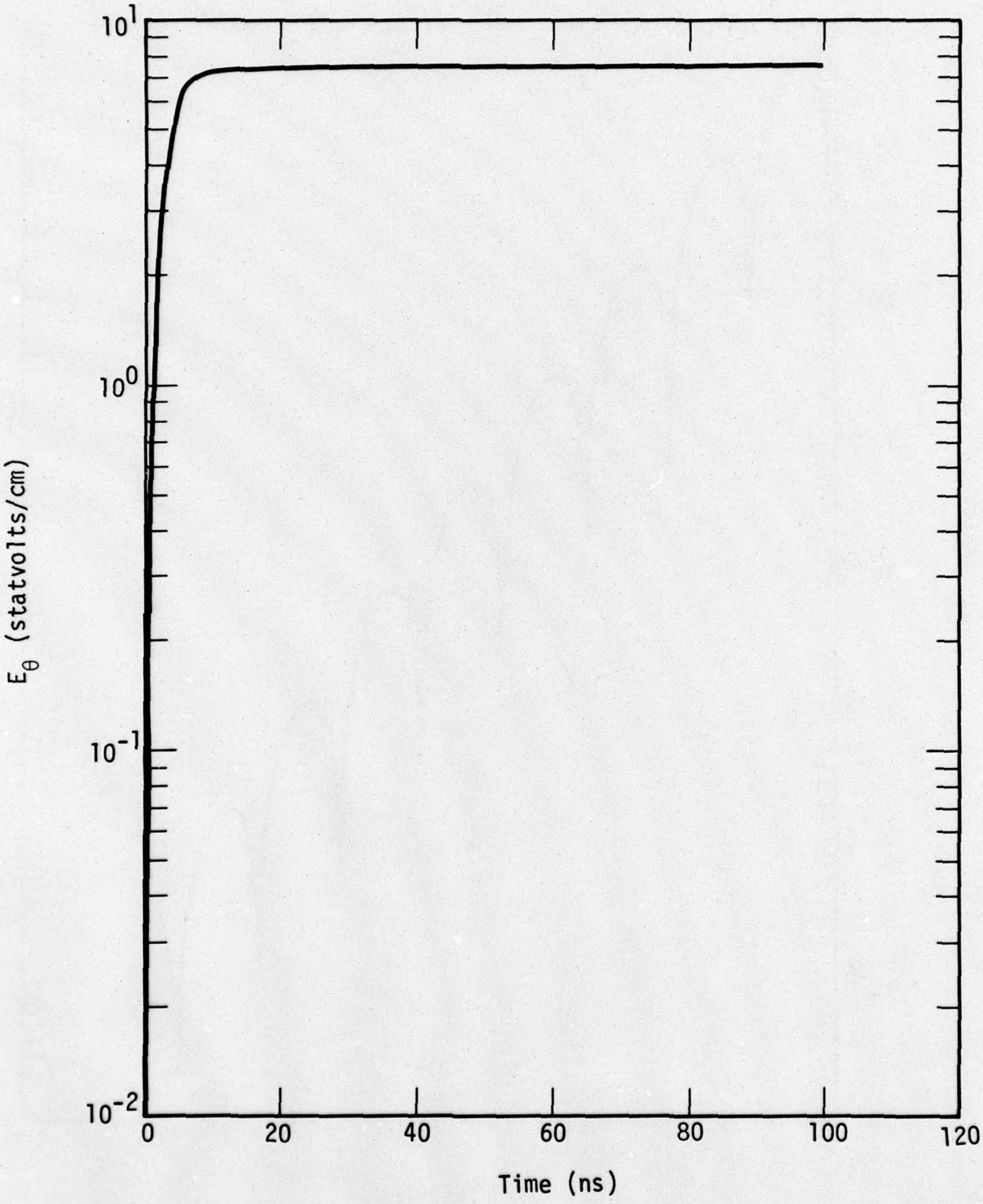


Figure 3. Theta electric field at r = 1.074 m, θ = 90°.

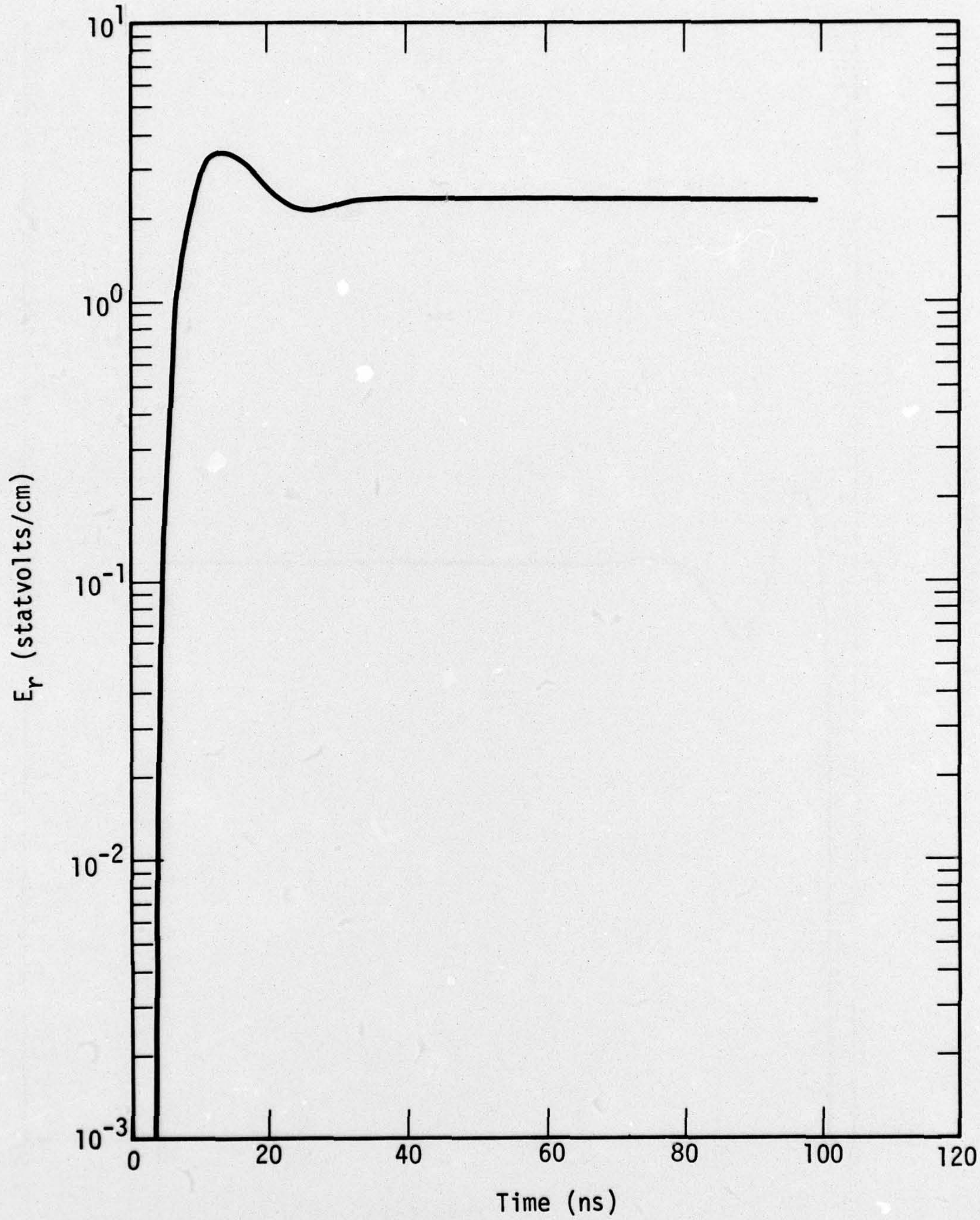


Figure 4. Radial electric field at r = 2 m, θ = 0°.

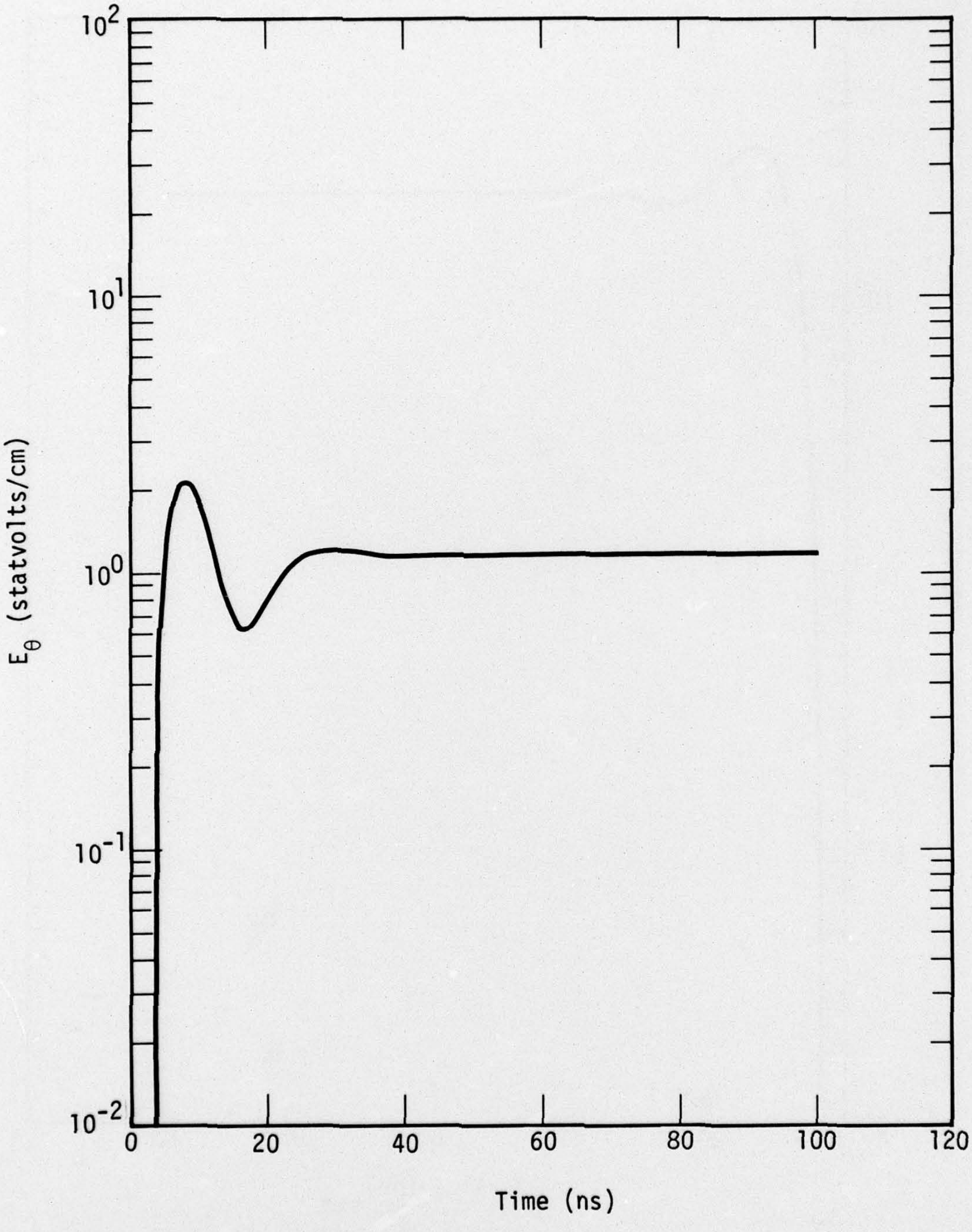


Figure 5. Theta electric field at r = 2 m, θ = 90°.

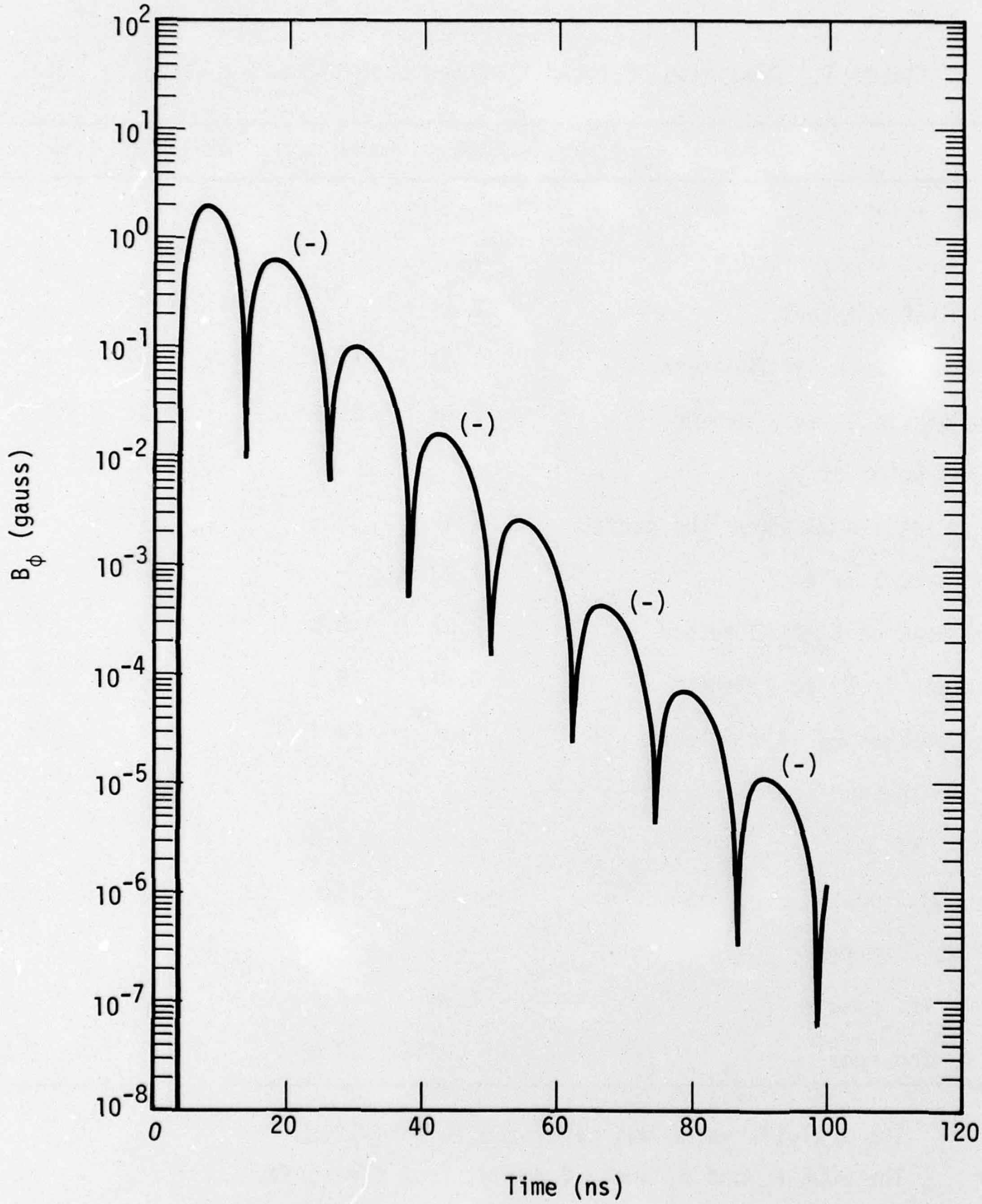


Figure 6. Azimuthal magnetic field at r = 2 m, θ = 90°.

Table 1. Comparison between MODE and analytic calculation.

	MODE	Time (ns)	Analytic	Time (ns)*
Final value of E_r				
-at the surface**	-109.	-	-107.	-
-at 2 meters	2.33	-	2.32	-
1st peak at E_r at 2 meters	3.48	13.4	3.49	13.5
1st dip in E_r at 2 meters	2.18	25.5	2.14	26
Final value of E_θ				
-at 7.4 cm above the surface	7.49	-	7.50	-
-at 2 meters***	1.23	-	1.16	-
1st peak of E_θ at 2 meters	2.22	8.0	2.15	8
1st dip in E_θ at 2 meters	0.671	16.5	0.626	17
2nd peak at E_θ at 2 meters	1.31	28.4	1.25	29
H_ϕ at the surface**				
1st peak	5.06	5.2	5.37	5
2nd peak	-1.07	16.0	-1.04	16.5
H_ϕ at 2 meters				
1st peak	1.98	7.6	2.00	7.5
2nd peak	- .625	17.5	- .617	17.5

* The analytic value was tabulated in 1 ns steps.

** The MODE E_r and H_ϕ are 3.8 cm out from the surface.

*** The MODE E_θ is 3.8 cm in from the outer boundary at 2 m.

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Commander in Chief
U.S. European Command, JCS
ATTN: ECJ6-P

Director
Defense Advanced Rsch. Proj. Agency
ATTN: NMR

Director
Defense Civil Preparedness Agency
Assistant Director for Research
ATTN: TS, AED

Defense Communication Engineer Center
ATTN: Robert Rostron
ATTN: Code R103P
ATTN: Code 1035, Nicholas A. Sica

Director
Defense Communications Agency
ATTN: Code 800, Fred Bond
ATTN: Code B205, George B. Adkins
ATTN: Code 430
ATTN: Code 930, Monte I. Burgett, Jr.
ATTN: NMR

Defense Documentation Center
Cameron Station
12cy ATTN: TC

Director
Defense Intelligence Agency
ATTN: DB-4C, Edward O' Farrell

Director
Defense Nuclear Agency
ATTN: DDST
ATTN: STSI Archives
ATTN: RATN
2cy ATTN: RAEV
3cy ATTN: STTL Tech. Library

Commander
Field Command
Defense Nuclear Agency
ATTN: FCLMC
ATTN: FCPR

Director
Interservice Nuclear Weapons School
ATTN: Document Control

Director
Joint Strat. Tgt. Planning Staff, JCS
ATTN: JLTW-2

Chief
Livermore Division Fld. Command DNA
Lawrence Livermore Laboratory
ATTN: FCPRL

National Communications System
Office of the Manager
ATTN: NCS-TS, Charles D. Bodson

DEPARTMENT OF DEFENSE (Continued)

Director
National Security Agency
ATTN: Orland O. Van Gunten, R-425

OJCS/J-3
ATTN: J-3, RDTA Br., WWMCCS Plans Div.

OJCS/J-5
ATTN: J-5, Plans & Policy, R & D Div.

DEPARTMENT OF THE ARMY

Director
BMD Advanced Tech. Ctr.
ATTN: RDMH-O, F. M. Hoke

Commander
BMD System Command
ATTN: BDMSC-TEN, Noah J. Hurst
ATTN: SSC-TEN, L. L. Dickerson

Dep. Chief of Staff for Rsch. Dev. & Acq.
ATTN: DAMA-CSM-N, LTC G. Ogden

Commander
Harry Diamond Laboratories
ATTN: DRXDO-TR, Edward E. Conrad
ATTN: DRXDO-RB, Joseph R. Miletta
ATTN: DRXDO-RCC, John E. Thompkins
ATTN: DRXDO-RCC, John A. Rosado
ATTN: DRXDO-RCC, Raine Gilbert
ATTN: DRXDO-EM, Robert E. McCoskey
ATTN: DRXDO-RBH, Stewart S. Graybill
ATTN: DRXDO-RC, Robert B. Oswald, Jr.
ATTN: DRXDO-TI, Tech. Lib.
ATTN: DRXDO-EM, George Merkel
ATTN: DRXDO-EM, R. Bostak
ATTN: DRXDO-EM, John Bombardt
ATTN: DRXDO-NP, Francis N. Wimenitz

Commander
Picatinny Arsenal
ATTN: SMUPA-ND-W
ATTN: SARPA-ND-C-E, Amina Nordio
ATTN: SARPA-TS-I-E, Abraham Grinoch
ATTN: SARPA-ND-N-D
ATTN: SMUPA-TN, Burton V. Franks
ATTN: SARPA-FR-E, Louis Avrami

Commander
Redstone Scientific Information Ctr.
U.S. Army Missile Command
3cy ATTN: Chief, Documents

Commander
TRASANA
ATTN: ATAA-EAC, Francis N. Winans

Director
U.S. Army Ballistic Research Labs.
ATTN: DRXBR-AM, Donald Eccleshall

Chief
U.S. Army Communications Sys. Agency
ATTN: SCCM-AD-SV, Library

DEPARTMENT OF THE ARMY (Continued)

Commander
U.S. Army Electronics Command
ATTN: DRSEL-TL-ME, M. W. Pomerantz
ATTN: DRSEL-NL-O-4
ATTN: DRSEL-GG-TD, W. R. Werk
ATTN: DRSEL-TL-IR, Edwin T. Hunter
ATTN: DRSEL-PL-ENV, Hans A. Bomke

Division Engineer
U.S. Army Engineer Div. Missouri Rvr.
ATTN: MRDED-MC, Floyd L. Hazlett

Commander-in-Chief
U.S. Army Europe and Seventh Army
ATTN: ODCSE-E, AEAGE-PI

Commandant
U.S. Army Field Artillery School
ATTN: ATSFA-CTD-ME, Harley Moberg

Commander
U.S. Army Foreign Science & Tech. Ctr.
ATTN: DRXST-ISI, Daniel W. McCallum, Jr.

Commander
U.S. Army Mat. & Mechanics Rsch. Ctr.
ATTN: DRXMR-HH, John F. Dignam

Commander
U.S. Army Materiel Dev. & Readiness Cmd.
ATTN: DRCDF-D, Lawrence Flynn

Commander
U.S. Army Missile Command
ATTN: DRCPM-PE-EG, William B. Johnson

Commander
U.S. Army Test and Evaluation Comd.
ATTN: DRSTE-NB, Russell R. Galasso
ATTN: DRSTE-EL, Richard I. Kolchin

DEPARTMENT OF THE NAVY

Chief of Naval Operations
ATTN: Code 604C3, Robert Piacesi
ATTN: Robert A. Blaise

Chief of Naval Research
ATTN: Code 464, Thomas P. Quinn
ATTN: Henry Mullaney, Code 427

Commander
Naval Air Systems Command
Headquarters
ATTN: Air-5202, Muriel L. Scarbough

Commander
Naval Electronic Systems Command
Naval Electronic Systems Cmd. Hqs.
ATTN: PME, 117-21
ATTN: PME, 117-T
ATTN: Code 5032, Charles W. Neill

Commander
Naval Electronics Laboratory Center
ATTN: Code 3100, E. E. McCown

DEPARTMENT OF THE NAVY (Continued)

Commanding Officer
Naval Intelligence Support Ctr.
ATTN: NISC-611

Director
Naval Research Laboratory
ATTN: Code 7706, Jay P. Boris
ATTN: Code 7701, Jack D. Brown
ATTN: Code 2627, Doris R. Folen
ATTN: Code 4004, Emanual L. Brancato
ATTN: Code 6631, James C. Ritter
ATTN: Gerald Cooperstein, Code 7770

Commander
Naval Sea Systems Command
ATTN: SEA-9931, Riley B. Lane
ATTN: SEA-9931, Samuel A. Barham

Commander
Naval Ship Engineering Center
ATTN: Code 6174D2, Edward F. Duffy

Commander
Naval Surface Weapons Center
ATTN: Code WA501, Navy Nuc. Prgms. Off.
ATTN: Code WA50, John H. Malloy
ATTN: Code 431, Edwin R. Rathburn
ATTN: Code 431, Edwin B. Dean

Commander
Naval Telecommunications Command
Nav. Tel. Com. Headquarters
ATTN: N-7, LCDR Hall

Commander
Naval Weapons Center
ATTN: Code 533, Tech. Lib.

Commanding Officer
Naval Weapons Evaluation Facility
ATTN: Lawrence R. Oliver

Commanding Officer
Naval Weapons Support Center
ATTN: Code 7024, James Ramsey
ATTN: Code 70242, Joseph A. Munarin

Director
Strategic Systems Project Office
ATTN: NSP-2431, Gerald W. Hoskins
ATTN: SP 2701, John W. Pitsenberger
ATTN: NSP-230, David Gold

DEPARTMENT OF THE AIR FORCE

Commander
ADC/DE
ATTN: DEEDS, Joseph C. Brannan

AF Geophysics Laboratory, AFSC
ATTN: Charles Pike
ATTN: LQR, Edward A. Burke

AF Institute of Technology, AU
ATTN: Library AFIT, Bldg 640, Area B

DEPARTMENT OF THE AIR FORCE (Continued)

AF Materials Laboratory, AFSC
ATTN: Library

AF Weapons Laboratory, AFSC
ATTN: SAB
ATTN: ELC
ATTN: EL, John Darrah
ATTN: ELA
ATTN: SAS
ATTN: SUL
ATTN: EL

AFTAC
ATTN: TES, Maj Marion F. Schneider

Commander
ASD
ATTN: ASD/ENESS, Peter T. Marth
ATTN: ASD-YH-EX, LtCol Robert Leverette

Headquarters
Electronic Systems Division, AFSC
ATTN: XRRT
ATTN: DCD/SATIN IV

Commander
Foreign Technology Division, AFSC
ATTN: ETET, Capt Richard C. Husemann

HQ USAF/RD
ATTN: RDQSM

Commander
Rome Air Development Center, AFSC
ATTN: P. Gianino

SAMSO/DY
ATTN: DYS, Capt Wayne Schober
ATTN: DYS, Maj Larry A. Darda

SAMSO/IN
ATTN: IND, Maj Darryl S. Muskin

SAMSO/MN
ATTN: MNNG, Capt David J. Strobel
ATTN: MNNH, Capt William M. Carra
ATTN: MNNH, Capt Michael V. Bell
ATTN: MNNG

SAMSO/SK
ATTN: SKF, Peter H. Stadler

SAMSO/XR
ATTN: XRS

Commander In Chief
Strategic Air Command
ATTN: XPFS, Capt Deraad
ATTN: NRI-STINFO, Library

ENERGY RESEARCH & DEVELOPMENT ADMINISTRATION

University of California
Lawrence Livermore Laboratory
ATTN: Tech. Info. Dept., L-3
ATTN: Hans Kruger, L-96
ATTN: Frederick R. Kovar, L-31
ATTN: Donald W. Vollmer, L-154
ATTN: Donald J. Meeker, L-545
ATTN: Louis F. Wouters, L-48
ATTN: William J. Hogan, L-531
ATTN: Walter W. Hofer, L-24

Los Alamos Scientific Laboratory
ATTN: Doc. Con. for Bruce W. Noel
ATTN: Doc. Con. for Donald R. Westervelt
ATTN: Doc. Con. for J. Arthur Freed
ATTN: Doc. Con. for John S. Malik
ATTN: Doc. Con. for Marvin M. Hoffman
ATTN: Doc. Con. for P. W. Keaton
ATTN: Doc. Con. for Richard L. Wakefield
ATTN: Doc. Control for Reports Lib.

Sandia Laboratories
Livermore Laboratory
ATTN: Doc. Con. for Theodore A. Dellin

Sandia Laboratories
ATTN: Doc. Con. for 5240, Gerald Yonas
ATTN: Doc. Con. for Elmer F. Hartman
ATTN: Doc. Con. for Org. 2315, James E. Gover
ATTN: Doc. Con. for 3141, Sandia Rpt. Coll.
ATTN: Doc. Con. for Org. 9353, R. L. Parker
ATTN: Div. 5231, James H. Renken
ATTN: Doc. Con. for Org. 2110, J. A. Hood

OTHER GOVERNMENT AGENCIES

Administrator
Defense Electric Power Admin.
Department of the Interior
ATTN: Document Control

Department of Commerce
National Bureau of Standards
ATTN: Sec. Officer for Judson C. French

Department of Transportation
Federal Aviation Administration
Headquarters Sec. Div., ASE-300
ATTN: Fredrick S. Sakate, ARD-350

NASA
ATTN: Code Res. Guid. Con. & Info. Sys.

NASA
Lewis Research Center
ATTN: Library
ATTN: Robert R. Lovell, MS 54-3

DEPARTMENT OF DEFENSE CONTRACTORS

Aerojet Electro-Systems Co. Div.
Aerojet-General Corporation
ATTN: Thomas D. Hanscome

Aeronutronic Ford Corporation
Western Development Laboratories Div.
ATTN: Donald R. McMorrow, MS G30
ATTN: Library
ATTN: J. T. Mattingley, MS X22

Aerospace Corporation
ATTN: C. B. Pearlston
ATTN: Norman D. Stockwell
ATTN: Frank Hai
ATTN: William W. Willis
ATTN: V. Josephson
ATTN: J. Benveniste
ATTN: Irving M. Garfunkel
ATTN: Julian Reinheimer
ATTN: Library

AVCO Research & Systems Group
ATTN: Research Lib., A830, Rm. 7201

Battelle Memorial Institute
ATTN: Robert H. Blazek

The BDM Corporation
ATTN: T. H. Neighbors

The Bendix Corporation
Navigation and Control Division
ATTN: George Gartner

The Boeing Company
ATTN: Donald W. Egelkrout, MS 2R-00
ATTN: Aerospace Library
ATTN: David L. Dye, MS 87-75
ATTN: Howard W. Wicklein, MS 17-11
ATTN: Kenneth D. Friddell, MS 2R-00
ATTN: Robert S. Caldwell, 2R-00

Booz-Allen and Hamilton, Inc.
ATTN: Raymond J. Chrisner

Brown Engineering Company, Inc.
Cummings Research Park
ATTN: John M. McSwain, MS 18

University of California at San Diego
IPAPS, B-019
ATTN: Sherman De Forest

Charles Stark Draper Laboratory, Inc.
ATTN: Richard G. Haltmaier
ATTN: Paul R. Kelly
ATTN: Kenneth Fertig

Computer Sciences Corporation
ATTN: Barbara F. Adams

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Computer Sciences Corporation
ATTN: Alvin T. Schiff
ATTN: Richard H. Dickhaut

Cutler-Hammer, Inc.
AIL Division
ATTN: Central Tech. Files, Anne Anthony

DePlomb, Dr. Eugene P.
ATTN: Eugene P. DePlomb

The Dikewood Corporation
ATTN: Tech. Lib.
ATTN: K. Lee

E-Systems, Inc.
Greenville Division
ATTN: Library, 8-50100

EG&G, Inc.
ATTN: Technical Library
ATTN: Hilda H. Hoffman

Exp. & Math Physics Consultants
ATTN: Thomas M. Jordan

Fairchild Camera and Instrument Corp.
ATTN: Sec. Dept. for 2-233, David K. Myers

The Franklin Institute
ATTN: Ramie H. Thompson

General Electric Company
Space Division
Valley Forge Space Center
ATTN: Larry I. Chasen
ATTN: Joseph C. Peden, VFSC, Rm. 4230M
ATTN: Daniel Edelman
ATTN: John L. Andrews

General Electric Company
Re-Entry & Environmental Systems Div.
ATTN: Robert V. Benedict

General Electric Company
TEMPO-Center for Advanced Studies
ATTN: Royden R. Rutherford
ATTN: DASIAC
ATTN: William McNamara
ATTN: John D. Illgen

General Electric Company
Aircraft Engine Group
ATTN: John A. Ellerhorst, E 2

General Electric Company
Aerospace Electronics Systems
ATTN: W. J. Patterson, Drop 233
ATTN: Charles M. Hewison, Drop 624

General Research Corporation
ATTN: John Ise, Jr.

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Georgia Institute of Technology
Georgia Tech. Research Institute
ATTN: R. Curry

Goodyear Aerospace Corporation
Arizona Division
ATTN: B. Manning

Grumman Aerospace Corporation
ATTN: Jerry Rogers, Dept. 533

GTE Sylvania, Inc.
Electronics Systems GRP-Eastern Div.
ATTN: Leonard L. Blaisdell
ATTN: Charles A. Thornhill, Librarian

GTE Sylvania, Inc.
ATTN: Comm. Syst. Div., Emil P. Motchok
ATTN: H & V Group, Mario A. Nurefora
ATTN: David P. Flood
ATTN: Herbert A. Ullman
ATTN: ASM Dept., S. E. Perlman

Hazeltine Corporation
ATTN: Tech. Info. Ctr., M. Waite

Hercules, Incorporated
ATTN: 100K-26-W, R. Woodruff

Honeywell, Incorporated
Government and Aeronautical
Products Division
ATTN: Ronald R. Johnson, A1622

Honeywell, Incorporated
Aerospace Division
ATTN: Richard B. Reinecke, MS 725-5
ATTN: Harrison H. Noble, MS 725-5A

Honeywell, Incorporated
Radiation Center
ATTN: Technical Library

Hughes Aircraft Company
ATTN: Kenneth R. Walker, MS D157
ATTN: John B. Singletary, MS 6-D133
ATTN: Billy W. Campbell, MS 6-E-110
ATTN: Tech. Lib.

Hughes Aircraft Company
Space Systems Division
ATTN: William W. Scott, MS A1080
ATTN: Edward C. Smith, MS A620

IBM Corporation
ATTN: Frank Frankovsky

IIT Research Institute
ATTN: Irving N. Mindel
ATTN: Jack E. Bridges

Institute for Defense Analyses
ATTN: IDA Librarian, Ruth S. Smith

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Intl. Tel. & Telegraph Corporation
ATTN: Alexander T. Richardson

Ion Physics Corporation
ATTN: Robert D. Evans

IRT Corporation
ATTN: R. L. Mertz
ATTN: James A. Naber
ATTN: Terry Flanagan
ATTN: Dennis Swift

Jaycor
ATTN: Eric P. Weenas
ATTN: Andrew Woods

Jaycor
ATTN: Robert Sullivan
ATTN: Catherine Turesko

Johns Hopkins University
Applied Physics Laboratory
ATTN: Peter E. Partridge

Kaman Sciences Corporation
ATTN: Albert P. Bridges
ATTN: W. Foster Rich
ATTN: Donald H. Bryce
ATTN: John R. Hoffman
ATTN: Library
ATTN: Walter E. Ware

Litton Systems, Inc.
Guidance & Control Systems Division
ATTN: R. W. Maughmer
ATTN: John P. Retzler
ATTN: Val J. Ashby, MS 67

Lockheed Missiles & Space Co., Inc.
ATTN: George F. Heath, D/81-14
ATTN: Benjamin T. Kimura, Dept. 81-14
ATTN: Edwin A. Smith, Dept. 85-85
ATTN: Dept. 85-85, Samuel I. Taimuty
ATTN: Philip J. Hart, Dept. 81-14

Lockheed Missiles and Space Company
ATTN: Clarence F. Kooi, Dept. 52-11

LTV Aerospace Corporation
Vought Systems Division
ATTN: Charles H. Coleman

LTV Aerospace Corporation
Michigan Division
ATTN: Tech. Lib.
ATTN: James F. Sanson, B-2

M. I. T. Lincoln Laboratory
ATTN: Jean L. Ryan
ATTN: Leona Loughlin, Librarian, A-082

Martin Marietta Aerospace
Orlando Division
ATTN: Jack M. Ashford, MP-537
ATTN: Mona C. Griffith, Lib., MP-30
ATTN: William W. Mras, MP-413

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Martin Marietta Corporation
Denver Division
ATTN: Ben T. Graham, MS PO-454
ATTN: J. E. Goodwin, Mail 0452

Maxwell Laboratories, Inc.
ATTN: Victor Fargo

McDonnell Douglas Corporation
ATTN: Paul H. Duncan, Jr.
ATTN: Stanley Schneider

Mission Research Corporation
ATTN: Daniel F. Higgins
ATTN: Roger Stettner
ATTN: William C. Hart
ATTN: Conrad L. Longmire
ATTN: Kenneth S. Smith
ATTN: James L. Gilbert
5cy ATTN: Tech. Library

Mission Research Corporation
ATTN: Larry D. Scott
ATTN: David E. Merewether

Mission Research Corporation-San Diego
ATTN: V. A. J. Van Lint

The Mitre Corporation
ATTN: Theodore Jarvis

Motorola, Incorporated
Semiconductor Group
ATTN: James R. Black

Motorola, Inc.
Government Electronics Division
ATTN: Tech. Info. Ctr., A. J. Kordalewski

Northrop Corporation
Electronic Division
ATTN: John M. Reynolds
ATTN: Vincent R. DeMartino
ATTN: Boyce T. Ahlport

Northrop Corporation
Northrop Research and Technology Ctr.
ATTN: David N. Pocock
ATTN: Library
ATTN: Orlie L. Curtis, Jr.

Northrop Corporation
Electronic Division
ATTN: Joseph D. Russo

Physics International Company
ATTN: Doc. Con. for Philip W. Spence
ATTN: Doc. Con. for John H. Huntington
ATTN: Doc. Con. for Charles H. Stallings
ATTN: Doc. Con. for Ian D. Smith

Pulsar Associates, Inc.
ATTN: Carleton H. Jones, Jr.

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

R & D Associates
ATTN: Richard R. Schaefer
ATTN: Leonard Schlessinger
ATTN: S. Clay Rogers
ATTN: William J. Karzas
ATTN: William R. Graham, Jr.

The Rand Corporation
ATTN: Cullen Crain

Raytheon Company
ATTN: Gajanan H. Joshi, Radar Sys. Lab.

Raytheon Company
ATTN: Harold L. Flescher

RCA Corporation
Government & Commercial Systems
Astro Electronics Division
ATTN: George J. Brucker

RCA Corporation
David Sarnoff Research Center
W. Windsor TWP
ATTN: K. H. Zaininger

RCA Corporation
Government & Commercial Systems
Missile & Surface Radar Division
ATTN: Eleanor K. Daly
ATTN: Andrew L. Warren

RCA Corporation
Camden Complex
ATTN: F. Van Keuren, 13-5-2

Research Triangle Institute
ATTN: Sec. Officer for Eng. Div., Mayrant Simons, Jr.

Rockwell International Corporation
ATTN: L. H. Pinson, FB41
ATTN: Donald J. Stevens, FA70
ATTN: N. J. Rudie, FA53
ATTN: James E. Bell, HA10
ATTN: J. Spetz
ATTN: George C. Messenger, FB61

Rockwell International Corporation
ATTN: John F. Roberts

Rockwell International Corporation
ATTN: T. B. Yates

Sanders Associates, Inc.
ATTN: 1-6270, R. G. Despathy, Sr., P. E.
ATTN: Moe L. Aitel, NCA 1-3236
ATTN: James L. Burrows

Science Applications, Inc.
Huntsville Division
ATTN: Noel R. Byrn

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Science Applications, Inc.
ATTN: J. Roger Hill

Science Applications, Inc.
ATTN: Charles Stevens

Science Applications, Incorporated
ATTN: William L. Chadsey

Sidney Frankel & Associates
ATTN: Sidney Frankel

Simulation Physics, Inc.
ATTN: Roger G. Little

The Singer Company
ATTN: Irwin Goldman, Eng. Management

Sperry Flight Systems Division
Sperry Rand Corporation
ATTN: D. Andrew Schow

Sperry Rand Corporation
Univac Division
ATTN: James A. Inda, MS 41T25

Sperry Rand Corporation
Sperry Division
Sperry Gyroscope Division
Sperry Systems Management Division
ATTN: Charles L. Craig, EV
ATTN: Paul Marraffino

Stanford Research Institute
ATTN: Mel Bernstein
ATTN: Setsuo Ddairiki
ATTN: Arthur Lee Whitson
ATTN: Philip J. Dolan

Stanford Research Institute
ATTN: Macpherson Morgan

Sundstrand Corporation
ATTN: Curtis B. White

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Systems, Science and Software
ATTN: David A. Meskan

Systems, Science and Software, Inc.
ATTN: Ira Katz
ATTN: Andrew R. Wilson

Systron-Donner Corporation
ATTN: Harold D. Morris

Texas Instruments, Inc.
ATTN: Donald J. Manus, MS 72

Texas Tech University
ATTN: Travis L. Simpson

TRW Systems Group
ATTN: Jerry I. Lubell
ATTN: Aaron H. Narevsky, R1-2144
ATTN: H. H. Holloway, R1-2036
ATTN: R. K. Plebuch, R1-2078
ATTN: Tech. Info. Center/S-1930
2cy ATTN: Robert M. Webb, R1-2410

TRW Systems Group
San Bernardino Operations
ATTN: J. M. Gorman, 520/114
ATTN: F. B. Fay, 527/710
ATTN: Earl W. Allen, 520/141

TRW Systems Group
ATTN: Donald W. Pugsley

United Technologies Corp.
Norden Division
ATTN: Conrad Corda

Westinghouse Electric Corporation
Defense and Electronic Systems Ctr.
ATTN: Henry P. Halapaca, MS 3525